Value Management and Model Pluralism in Climate Science[*]

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Abstract. Non-epistemic values pervade climate modelling, as is now well documented and widely discussed in the philosophy of climate science. Recently, Parker and Winsberg have drawn attention to what can be termed "epistemic inequality": this is the risk that climate models might more accurately represent the future climates of the geographical regions prioritised by the values of the modellers. In this paper, we promote value management as a way of overcoming epistemic inequality. We argue that value management can be seriously considered as soon as the value-free ideal and inductive risk arguments commonly used to frame the discussions of value influence in climate science are replaced by alternative social accounts of objectivity. We consider objectivity in Longino's sense as well as strong objectivity in Harding's sense to be relevant options here, because they offer concrete proposals that can guide scientific practice in evaluating and designing so-called multi-model ensembles and, *in fine*, improve their capacity to quantify and express uncertainty in climate projections.

Keywords. climate models; multi-model ensemble; uncertainty quantification; model pluralism; scientific objectivity; values in science; value-free ideal; strong objectivity.

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1 Introduction

Non-epistemic values – e.g. social, political, economic or ethical values – pervade climate modelling, as is now well documented and widely discussed in the philosophy of climate science (see Biddle and Winsberg 2009; Winsberg 2012; Intemann 2015; Winsberg 2018a; Winsberg 2018b, chap. 9, on value influence in General Circulation Models; see Frisch 2013 on Integrated Assessment Models; see Parker and Lusk 2019; Lusk 2020 on climate services; but see also Betz 2013; John 2015; Jebeile 2020 on value influence within the IPCC Assessment Reports). Non-epistemic values can influence the purposes and priorities of model development and ultimately the selection of entities and processes to be represented within the models, as well as the choice of explicit dynamics equations or parameterisations used to represent those entities and processes (Parker and Winsberg 2018, 128). It is widely assumed that such value influence can endanger objectivity in model-based climate projections; and yet objective projections are precisely what is required for policy-makers to decide what actions to take.

Parker and Winsberg (2018) have recently demonstrated how, by shaping climate models, the influence of values in model development also affects the quantification of uncertainty which, among other policy-relevant inputs, is used to calculate the probabilities of future climate projections. For them, this is not a case of "wishful thinking" – i.e., that values influence models such that projections based upon them reveal how modellers would like things to be in the future, rather than how likely those things are (see Brown 2013; Intemann 2015, 221) – rather, this is an expression of what can be termed "epistemic inequality." Epistemic inequality is the risk that models might more accurately represent the future climates of the geographical regions and sources of concern prioritised by the values of the modellers, thus making some people better informed than others. This problem is not only epistemic but also ethical, in that "the value influence ... could in some cases be complicit in perpetuating certain kinds of power imbalances and injustices" (Parker and Winsberg 2018, 135).

We agree that epistemic inequality can be caused by uncontrolled value influence in climate modelling. We also think that this issue contravenes the missions of the expert panels commissioned by international agencies, namely that they must instruct everyone equally about the future of the earth. Moreover, the wide dissemination of scientific findings as well as the promotion of the independence of science are among the ethical principles adopted by the UNESCO *Declaration of Ethical Principles in relation to Climate Change* (UNESCO 2017, Articles 7 and 8). Taking this problem seriously, therefore, in this paper we promote value management as a way of overcoming epistemic inequality. Such a solution, though, can hardly be countenanced within the common framework employed in the literature on values in climate modelling, i.e. a framework characterised by insistence on the value-free ideal and the employment of inductive risk arguments. An alternative account of objectivity is therefore required if we are to countenance the strategy of value management. In this paper, we argue that alternative social accounts of objectivity, borrowed from feminist epistemologies, can open up the space for value management and so help to mitigate the problem of epistemic inequality.

The paper is organised as follows. First, we show how epistemic inequality arises in individual models, be they General Circulation Models or Regional Climate Models, in Multi-Model Ensembles, and in the historical coverage of the climate data used to validate models (Section 2). Multi-Model Ensembles constitute one of the ensemble-based approaches typically used in climate science, making model pluralism central to this scientific domain. Multi-Model Ensembles produce projections that in turn, by virtue of being multiple, are used to quantify climate uncertainties in terms of probabilities, and also to explore future climate possibilities.

Second, we argue that model pluralism offers the basis for value management provided that Multi-Model Ensembles are understood (rightly so, in our view) as being collections of aggregated expert judgements. In light of this interpretation, we contend that the value-free ideal and the inductive risk arguments, commonly used to frame the discussions of the appropriate place of values in climate science, should be replaced by alternative social accounts of objectivity (Section 3).

Third, we assume that the alleviation of epistemic inequality is supported by higher cognitive diversity within the sampling of models in ensembles, and, following Rolin (2019), that cognitive diversity can result from certain kinds of social diversity. Based on this assumption, we explore the ways social accounts of objectivity can promote social diversity in a relevant way. As we argue, objectivity in the sense of Longino (1990, 2002), and strong objectivity in the sense of Harding (1991, 1992, 1995), are particularly suitable for our purposes here, for reasons extending beyond purely theoretical or feminist considerations. Both accounts indicate how objectivity can be strengthened specifically by the synergistic influence of multiple values in a way that is compatible with model pluralism in climate science (Section 4).

2 Value influence in climate models: the problem of epistemic inequality

Values can orientate the choice of purposes and priorities in climate models. Such influence takes place in climate modelling because the domain of climate knowledge is both complex and uncertain, and therefore the relevant components and processes of the climate system cannot all be represented with equal accuracy. Limited computer power and incomplete process understanding require the use of simplifying assumptions. The major problem, then, is that this influence of values creates epistemic inequality. In this section we examine the form that this problem takes in individual models and in ensembles of models used to quantify uncertainty and calculate probabilities, at the scale of both global and regional climate modelling.

2.1 Climate models

First let us describe in more detail how values influence climate models taken individually. Within models, simplifying assumptions are necessary. These include omissions and idealisations of climate components, as well as parameterisations and choices of parametric values in model tuning. Parameterisations significantly contribute to modellers' uncertainty in climate projections. A parameterisation can be defined as a "mini-model" (Lloyd 2015, 61) within the larger model, providing an approximate mathematical description of sub-grid physical, biological, or chemical processes that does not immediately derive from the equations of motion and radiation. These processes include, among others, cloud processes, turbulent diffusion, and biological phenomena such as photosynthesis and evapotranspiration.

Because no set of simplifying assumptions seems unequivocally most adequate for representing the climate system, those assumptions are underdetermined (or epistemically unforced), and therefore the decision to make any given simplification can be influenced by non-epistemic values. As Parker and Winsberg (2018) argue, values partly determine the purposes and priorities in climate modelling, and ultimately the decisions concerning which processes to represent in the models and how they should be described via explicit dynamics equations, parameterisations, and other more or less well justified idealisations (Parker and Winsberg 2018, 128).

Likewise, the choice of parameter values is not entirely dictated by first principles and need to be tuned to optimise the performance of the model. Given the simplifying assumptions, a model cannot be calibrated to perfectly capture all observations. For this reason, within a model, the decision to accurately represent one part of the climate system often comes with some sacrifice of representational accuracy in some other part of the system. In other words, the way values influence individual models often takes the form of a modelling trade-off (Winsberg 2012; Intemann 2015). Thus, modellers may give priority to the accuracy of geographical regions and corresponding variables that are relevant given their own values and interests. Parker and Winsberg (2018, 128) exemplify this phenomenon by considering the case of global weather forecasting models. Producing forecasts more accurately for the country in which the modellers work and live may be deemed a higher priority than, for example, predicting the weather in Antarctica; depending on where the modellers are, producing rainfall and surface temperature forecasts may be more important than specifying high altitude wind speeds.

Parker and Winsberg (2018) argue that the way values exert an influence in climate modelling does not necessarily constitute wishful thinking, as it does not drive the analysis toward specific conclusions about the probability of a hypothesis. Prioritising the predictive accuracy of the rainfall module in a model would not make increase the probability estimated for the hypothesis that it will rain in the region of interest. But value influence does have a genuinely important consequence, i.e. the phenomenon we have referred to as epistemic inequality. Reducing idealisations that more particularly affect high-priority variables (and thereby particular climatic phenomena) leads to inaccuracies elsewhere in variables of lower priority. Hence, the problem arises that the people whose interests and values shape the purposes and priorities of climate models may be better informed about their own climate fate than that of others, and consequently better prepared to respond to future risks.

> To give a simple but stark example, if some African countries only have access to model-based global weather forecasts produced in North American and Western European countries, none of which considers accurate simulation of rainfall in those African countries to be a high priority, and if people in those African countries consequently receive forecasts of the probability of rainfall that are less skillful due to this inattention, then this may disadvantage them, compared to people living in North American and Western Europe, when it comes to identifying and responding to e.g. flood risks, droughts, etc. In this way, the value influence that we identified could in some cases be complicit in perpetuating certain kinds of power imbalances and injustices. In the extreme, high-priority variables might be selected with this very aim in mind. (Parker and Winsberg 2018, 135)

The values that influence climate models might be the private values of the modellers, but they could also be common values shared by the research group, the institution, or even the scientific community to which the modellers belong. They might even be values shared by people with the same culture or living in the same country as the modellers. In any case, it is reasonable to think that values differ between research groups of different countries. Individual models bear the mark of the regional interests prioritised by the values of the modellers (be they shared by the research group, institution, scientific community, or the country to which the modellers belong). For the sake of illustration, we might reasonably suppose that UK models are particularly good at predicting the future climate of the UK. Thatcher's government justified the creation of the Hadley Centre as a contribution to the global effort to study climate change (Thatcher 1990), but at the same time the Hadley Centre is partly funded in order to advise the government about politics centered on British concerns. We can, of course, infer that the same is true for all those countries that provide extensive funding for climate modelling.

The problem arises because climate change is a global phenomenon, yet the focus on a specific part of the system that is of higher priority to the modellers may lead them to unintentionally neglect other parts. One way to overcome the problem would be for each country to develop its own national modelling programme; yet, as we know, this is hardly possible since countries do not have equal economic resources and scientific infrastructures. The problem here is epistemic and ethical, since it may reinforce existing power imbalances and injustices (Parker and Winsberg 2018, 135). And yet, as has been documented (see Field et al. 2014), communities and populations are unequally affected by climate change, and the most vulnerable to climate impacts are often the least responsible for them, as well as the least informed and prepared.

2.2 Ensembles of General Circulation Models

We want to highlight the way epistemic equality manifests in the ensembles of models which are used to quantify uncertainty and calculate probabilities. Climate scientists communicate probabilities about climate projections to policymakers, and these probabilities are supposed to reflect a collective judgement regarding the scientists' uncertainty about certain aspects of climate change. As it happens, in climate science, ensembles of experiments with different models play a central role in determining these probabilities.

In particular, Multi-Model Ensembles (MMEs), on which we focus, are used to quantify the structural uncertainty which is due to the choice of modelling assumptions – and simplifying assumptions more particularly – used to represent the processes at work in the climate system. MMEs are intended as a means to explore structural uncertainty in that, within MMEs, models vary from each other in their simplifying assumptions, e.g. the number of processes they represent, their idealisations and parameterisations, and the way they have been calibrated or "tuned". Thus, model pluralism is an essential character of climate science.

Today the reference framework for MMEs is the Coupled Model Intercomparison Project (CMIP). In this framework, MMEs are composed of General

Circulation Models (GCMs) (e.g. CCSM, HadGEM, IPSL-CM) built by modelling centres all over the world (e.g. National Center for Atmospheric Research, Met Office Hadley Centre, Institut Pierre Simon Laplace). They are used to inform the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC): specifically, they serve the IPCC's Working Group 1, which focuses on the physical climate system.

Within an MME, no model can stand out as the indisputably best with respect to all the relevant performance metrics. The plurality of models nonetheless provides an opportunity to deliver probabilities to policy-makers. The attempt to take advantage of multiple models is justified in the IPCC reports by the assumption that all models within an MME are "equally plausible". Climate models are considered "alternative and equally plausible numerical representations, solutions and approximations for modelling the climate system, given the limitations in computing and observations" (Collins et al. 2013, 1036). Consequently, for a given scenario, similarly forced models in an MME produce a range of plausible climate change projections, called the "model spread", that in turn is used to quantify structural uncertainty. Probability distribution functions for key variables (e.g. mean surface temperature or precipitation) can be calculated from the average projection and the model spread (see Parker 2010).

A well-known criticism of this method in the climate science community is that the MMEs of CMIP are "ensembles of opportunity" (Meehl et al. 2007, 754; Tebaldi and R. 2007; Knutti et al. 2010). MMEs are indeed not primarily designed to explore structural uncertainty: they are not random – nor systematic and comprehensive – samples of independent models. Rather, they are assembled from the available models developed by research groups around the world that conform to the standards imposed by CMIP.

In order to see how the problem of epistemic inequality can be expressed here, we need to examine the geographical origin of the models that usually compose MMEs. In CMIP5, among twenty-three selected models, seven are from the United States, three from Japan, two from Canada, two from France, two from the UK, two from China, one from Germany, one from a collaboration between Germany and South Korea, one from Norway, one from Australia, and one from Russia. More models have been developed in CMIP6, for which contributions have been made from additional research groups in Brazil, Cyprus, Denmark, Finland, India, Ireland, Italy, Netherlands, Portugal, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Taiwan, and Thailand (see CMIP6 2021). Still, very large regions of the world are represented by these few candidates, for instance, South America, Russia, and Africa. The distribution of models here is not representative of the entire human population.

Participation in CMIP depends of course on the economic resources and the scientific infrastructure available in a given country. The interests and values of the countries that are not represented by the research groups involved in CMIP therefore might not be addressed or taken into account in the models. Given the locations of research infrastructures – but also given the heritage of data collection infrastructures – less attention is paid to African regions (James et al. 2018). The problem is not only a problem of lack of attention: it is also a risk of bias in favour of the interests of the richest countries over less well represented interests. Values influence the choices of representation in models in a way that can affect the sampling or the weighting of models in an MME, and thereby bias the quantification of structural uncertainty and the calculation of probabilities. And yet it is crucial, in a context of support for political decisions, to reflect varied local needs in the purposes and priorities of the models that are supposed to justify such political decisions.

2.3 Ensembles of Regional Climate Models

Both policy-makers and climate modellers are interested in geographically refined information, in contrast to the global climate information provided by GCMs. This geographical refinement is called "downscaling". One approach to this goal consists in nesting a so-called "Regional Climate Model" (RCM) within the GCM grid. Similar to the GCM, the RCM encodes dynamical equations for the motion of the atmosphere and the ocean but with a higher-resolution mesh that is restricted to a region (e.g., Europe, North Africa). The RCM may include more emphasis on local processes (e.g., snow texture). GCMs are then used to provide initial and lateral boundary conditions to the RCM. Some RCMs are directly derived from a GCM and share large portions of code with it; others have been developed more independently.

Ensemble-based approaches are also used at the regional scale in order to provide uncertainty quantification and probabilities concerning future local climates – and more particularly variables, indices, and extremes in terms of frequency, intensity, or duration period in days. The regional counterpart of the CMIP, i.e., the Coordinated Regional Climate Downscaling Experiment (CORDEX), aims to provide comprehensive regional climate projections for all continental-scale land areas of the globe. For example, EURO-CORDEX coordinates the downscaling of the CMIP models to the European region (for given emission scenarios). One might think that, in the context of regional modelling, the problem of epistemic inequality is aggravated because not all countries can develop RCMs and predict the climate future at the local scale of interest (if they cannot at the very least develop their own GCMs). However, fourteen regions are respectively covered by its dedicated CORDEX programme, i.e., South America, Central America, North America, Europe, Africa, South Asia, East Asia, Central Asia, Australasia, Antarctica, Arctic, Mediterranean, Middle East North Africa, and South-East Asia (CORDEX 2021).

Nonetheless, it appears that the problem of epistemic inequality occurring at the scale of GCMs and MMEs of GCMs can still partly be transposed to RCMs (see also Shepherd and Sobel 2020 about epistemic inequality in the regional context). Because RCMs are often "nested" within a GCMS, biases, regional gaps, or shortcomings within GCMs may indeed be transferred to ensembles of RCMs. "For instance, if an RCM is downscaling a GCM with large errors in the circulation over the region of interest, the downscaled results will be influenced by this bias in the large-scale field" (CH2018 2018, 49). Therefore, the problem of epistemic inequality seems simply to be transposed to the regional scale. That said, RCMs are usually supposed to correct some of the bias conveyed by the GCMs that are taken as a starting point.

Nation-scale modelling projects aim to further correct the biases remaining in RCMs for the region of interest. For the sake of illustration, in the Swiss climate scenarios (CH2018 2018), refinement to a 2 km x 2 km grid is the aim, whereas the resolution of the CORDEX programme is around 12 or 50 km (while GCMs have a resolution of around 100 km). Importantly, the starting pool of RCMs used in the Swiss scenarios is a selection of RCMs from EURO-CORDEX: RCMs having "problematic or unrealistic" results in regions or variables relevant for Switzerland are excluded (CH2018 2018, 49-53). To give just one example, as the analysis of snowfall and snow cover is highly relevant in Switzerland, "Simulations showing substantial and unrealistic snow accumulation over the Alps were removed from the model set used in CH2018" (CH2018 2018, 49). The needed selection makes the starting pool of RCMs more limited and therefore may affect the statistical quality of the sampling; a technique called pattern scaling thus aims to provide a more trustful representation of model uncertainty. For the Swiss scenarios, a bias-correction method – called quantile mapping – is therefore applied in parallel to the downscaling process (see Jebeile et al. 2020 for a discussion of the impacts of downscaling techniques on understanding). But those corrections depend heavily on the availability of empirical data, and historical coverage of climate data is also not equally distributed.

2.4 Historical coverage of climate data

Lastly, then, we point out that epistemic inequality is not only due to the choice of purposes and priorities in climate modelling, but also due to the historical coverage of the empirical data that are used in turn to understand past and present climate, but also to calibrate and validate climate models.

Epistemic inequality in climate science can occur in the way climate models are designed, but also in the way climate data are produced. Brönnimann and Wintzer (2018) show that climate data themselves are context-dependent: they "carry imprints of social, political, economic and technological factors" (2018, 4). For instance, data coverage of meteorological measurements is "neither a random sample of the Earth's surface nor a planned product" (2018, 4). History has influenced the quantity and the locations of data measurements. Data coverage thus mirrors population density, national economic development, world trade, colonial history, wars, etc. And this is also true for satellite data that are partly measured by (public and private) enterprises, which have their own interests and agenda. The authors emphasise that "Unequal spatial coverage is not just a data problem, but also one that affects climate justice" (2018, 4). As they point out, among other problems,

> unequal climate data coverage has political implications such as the procedure injustice in climate policy due to imbalance of observations ... For instance, developing countries with only short climate records suffer from a disadvantage when trying to prove adverse

> climate effects. When sophisticated methods are used to generate globally complete, technical, “objective” long-term data products such as reanalyses, this imbalance is partly alleviated, but the imbalance in the underlying data remains or at least transforms into larger uncertainties ... (Brönnimann and Wintzer 2018, 4)

In a nutshell, the degree of epistemic inequality depends on the geographical sampling of models in MMEs. If all the models in MMEs are developed by research groups that share similar interests and values, then the privileged access to climate information will remain unequal. On the contrary, if global coordination can encourage research groups to explore geographical diversity, then the problem may be solved; this is an option we explore in the remainder of the paper.

3 Beyond inductive risk arguments and common interpretation of model pluralism

A possible practical solution to overcome epistemic inequality is to coordinate the development of models and data collection campaigns around the world. We posit that the model pluralism that characterises climate science can be a real opportunity to coordinate the regions covered by the models and more broadly the multiple interests and values of communities and populations. For Lenhard and Winsberg (2010), model pluralism in climate science is inevitable, because confirmation holism – with its sources in fuzzy modularity, kludging and generative entrenchment – makes it impossible to make climate models within an ensemble converge, and therefore climate policy should “accept model pluralism as a useful information for the decision process” (2010, 261). For us, model pluralism in climate science is also an opportunity to correct for shortcomings that any individual model simply cannot avoid. In what follows, we focus on the development of models; it seems to us that data collection campaigns are already tending to cover more geographical regions, although the gaps in historical data can hardly be filled.

Coordination of the development of models requires epistemological reflection on the ways to handle values in climate modelling. However, the predominant conceptual framework in philosophical discussions about values in climate science relies essentially on the inductive risk arguments that are taken as the standard objection to the idea that we should strive towards the value-free ideal, and on a certain interpretation of model pluralism in climate science that needs to be revised. Yet, as we are about to argue, this predominant conceptual framework falls short for the reasons we now provide.

3.1 Inductive risk arguments

First of all, let us focus on the inductive risk arguments often considered as the major challenge to the value-free ideal. The ideal of value-free science states that non-epistemic values must not interfere with the production of scientific knowledge. Such values are often said to be contextual. Being social, political, economic or ethical in nature, they are thus supposed to be non-truth-conducive, and, according to the ideal of value-free science, they should not contribute to assessing the extent to which a representation matches its target. This ideal is supposed, in turn, to dissociate the scientists' knowledge production from the attribution of values, where the latter is to be delegated to policy-makers or other representatives of the stakeholders' best interests. However, as is now widely acknowledged, non-epistemic values inevitably play some role in the practice of science; the distinction between epistemic and non-epistemic values is even debatable (see Longino 1996). In the initial inductive risk argument formulated by Rudner (1953), scientists can legitimately refer to values to assess the strength of available evidence with respect to accepting or rejecting something as knowledge. Douglas (2000) further argues that scientists can legitimately refer to values in justifying their methodological choices. For example, let us consider two instruments that can be used to measure the percentage of rats that contract a disease once inoculated by a given substance; one is prone to false positives, while the other is prone to false negatives. The choice between the two depends on the kind and the level of risk one is ready to take, which are in turn determined by non-epistemic values.

In the philosophy of climate science, inductive risk arguments are commonly taken as the starting point for discussions on values in climate modelling. Importantly, Winsberg (2012, 2018b, chap. 9, 2018a), and Parker and Winsberg (2018) extend Douglas's inductive risk argument (2000) to the case of climate science. The authors focus on ensemble-based probabilities concerning future climates as the relevant and supposedly objective input that climate science can deliver to policy-makers. In particular, it is argued that "ensemble sampling approaches fail for just the reasons that Douglas has made perspicuous: because they ossify past methodological choices (which themselves can reflect balances of inductive risk and other social and ethical values) into 'objective' probabilistic facts" (Winsberg 2012, 125).

The inductive risk arguments focus on managing the risk of errors that may have detrimental social or moral consequences (see de Melo-Martín and Intemann 2016 pointing out a shortcoming in inductive risk arguments). However, while values can indeed help in discriminating between modelling methodologies with acceptable errors and those with undesirable errors, they may well play another important positive role by integrating a diversity of points of view within the production of knowledge, and in particular climate knowledge. They can thus constitute valuable cognitive resources with which to proceed when doing science. This is a cornerstone of feminist epistemologies. Furthermore, feminist epistemologies insist on knowledge being situated. Specifically, promoting equal attention to all regions of the world in climate models is a value that promotes epistemic equality and, hopefully, climate justice. Intemann (2015) persuasively argues that social and ethical values can legitimately influence climate model construction, and proposes they can do so when they promote democratically-endorsed social and epistemic aims of research. Hence, the inductive risk arguments can and should be replaced by alternative accounts that we will discuss below. First, though, let us discuss an additional revision needed within the predominant conceptual framework.

3.2 Model pluralism

Within the common framework, the models in an MME are considered to be approximate and distorted (mathematical) versions of some background information. Each is understood as a plausible candidate for *the* adequate model: therefore, an MME constitutes a "collection of best guesses" (Parker 2013). This view is closely related to the definition of structural uncertainty itself, i.e., uncertainty about what an adequate model structure would be. By quantifying structural uncertainty, the MME can be used to assign probabilities to hypotheses concerning future climates – even if, as is recognised, this is only done imperfectly in that the MME is an "ensemble of opportunity".

While adopting a Bayesian account in which ensemble-based probabilities result from expert judgements about confidence in the evidence and the ensemble-based methodology, and are updated in light of new evidence, Parker and Winsberg (2018) crucially highlight that the ensemble-based probabilities are conditional on the experts' background information. While scientific models are expected to be used as surrogates for background knowledge, they cannot strictly speaking constitute background knowledge themselves, because in many ways they approximate and distort the scientists' best theoretical knowledge of all the processes at work in the climate system. The idealisations and parameterisations that scientists apply in their models are shaped by the purposes and priorities they have previously set, given their non-epistemic values. Crucially, the authors claim,

> Because these scientific models often deviate from background knowledge in ways that are in part dependent on non-epistemic values, the probabilities estimated via these studies also turn out to be dependent on non-epistemic values in the sense that, if the non-epistemic values had been different, so would have the estimated probabilities, even with the same background knowledge. (Parker and Winsberg 2018, 127)

In that account, value influence is understood to operate on each individual model as a form of "noise" in the Bayesian framework: values create a stochastic deviation from background knowledge since they orientate purposes and priorities through the choices of representation. Even if the values are morality-conducive, democracy-conducive, etc., their influence seems to be still considered as mere deviation. Furthermore, the deviation seems to be considered "arbitrary" since the values have influence over the choices of representation in a non-concerted and non-coordinated manner.

However, while model plurality in climate science is commonly interpreted as a collection of mathematical structures, we argue it can be better understood as a collection of representative sets of expert judgements. This interpretation derives from the understanding that climate science is a collective and multidisciplinary epistemic enterprise in which actors depend upon each other, and that, incidentally, there is a natural development of the philosophy of climate science toward the perspective of social epistemology (see also Winsberg 2018b, chap. 13).

Models are built on expert judgements while themselves delivering a special kind of expertise about future climate to policy-makers; in turn, expert knowledge includes observations, data-driven models, process-based models and their outputs, as well as subjective judgements. Expert judgments are also used to decide whether models perform well. Given a specific set of observations, the likelihood of a given model is not straightforwardly defined. No climate model generates output which is so realistic that an expert could not, after inspection of all its output, recognise that it is a simulation and not the real world (Rougier 2007). In other words, at face value, the likelihood of any model, given all the knowledge a climate scientist may have about the climate, is zero. However, certain outputs, if properly aggregated (global or regional averages) or pre-processed (e.g., considering deviations from a reference value) may appear to match observations well enough to generate a usable likelihood function. Implicitly, such aggregations or post-processing reflect judgements about what the model is adequate for, which again may be value-loaded, and so are probabilities delivered as the outcome of the Bayesian process.

This said, we argue that the conditions which inject non-epistemic values into information delivered to the public remain relevant irrespective of the adoption of a Bayesian framework. They are therefore more general than those which pertain to the definition of a likelihood function. The key elements are as follows. First, that individual models are developed according to priorities set by institutional policies: they are calibrated and evaluated based on datasets which are the result of a socio-historical process. Second, that the way ensembles of models are processed reflects judgements on model adequacy and depends, again, on available observation datasets. For example, the choice of benchmarking criteria for accepting or rejecting models or perhaps weighting them in an ensemble is value-loaded. Injection of non-epistemic values is thus unavoidable, yet without prejudice to the scientists' integrity and disinterestedness (Rougier and Crucifix 2014).

MMEs inform our judgements on climate change, and they are therefore implicitly viewed as collective judgements. However, judgements and non-epistemic values naturally permeate ensembles of model outputs following a non-straightforward process that may involve the "social dynamics underlying scientific practices in climate modelling" (Jebeile and Crucifix 2020, 47), and thereby incorporate sociological effects such as conformism and historical legacies.

Models are influenced by values that reflect the history and scientific culture of the research centres – including past and present scientists, specialties, main projects, etc. Because expert judgements are situated, sampling models also means sampling the non-epistemic values and other research contingencies that may influence scientists. An MME is therefore a collection of aggregated judgements that are representative of the research centres' history and scientific culture. In such a framework, value influence is not a stochastic deviation from background knowledge: it is a source of diversity of points of view representative of the research centres' history and scientific culture. Hence, social accounts of objectivity seem more appropriate as a means to grapple with the values implicit in climate modelling.

In brief, we believe that the value-free ideal is not only unreachable — sources of non-epistemic values are abundant in representations of such a complex object as the climate — but perhaps even not desirable given the goal of informing policies which are not value-free and for which decision-makers must be accountable. By the same token, however, uncontrolled value influence is likely to cause epistemic inequality and misinform efforts for climate justice. Yet the inductive risk arguments and the common interpretation of model pluralism fall short in accounting for value management. As we will now argue, such value management becomes feasible once we adopt an alternative social account of objectivity. In the next section, we consider alternative accounts of objectivity borrowed from feminist epistemologies that can help us to design proper systems for value management in climate modelling.

4 Social accounts of objectivity for value management

Once we adopt the view that the ensemble of models can be interpreted as the diverse set of representative viewpoints informed by expert judgments, we can design a system for the sampling of models within an ensemble which resembles the elicitation of expert judgements. The overall idea is then to select the relevant diversity of points of view. In this section, we explore the ways social accounts of objectivity can promote a diversity of relevant viewpoints.

4.1 Cognitive diversity and social diversity

We start with the conceptual distinction highlighted by Rolin (2017, 2019) between cognitive diversity and social diversity. This distinction is useful to investigate ways to manage values in climate modelling, since climate modelling is undertaken internationally by multiple research groups that share scientific cultures and aims but also differ in their specialties and in some of their interests and values.

> A community or a group is cognitively diverse when its members have, for example, different research styles and skills, different perspectives on the subject matter of inquiry, or access to different bodies of empirical evidence. A community or a group is socially diverse when its members have different non-epistemic values, such

> as moral and political values, or different social locations, such as gender, ethnic identity, nationality, and race. (Rolin 2019, 158)

Thus, cognitive diversity can be thought of as diversity in research programmes, scientific theories, scientific perspectives, or scientific methodologies. In the case that interests us, what we want in MMEs is to reach a certain cognitive diversity that is a diversity of relevant purposes and priorities addressed in the models. Some forms of cognitive diversity can be verified or even improved without much reference to non-epistemic values. For example, one may verify that different types of convection schemes, judged to be equally plausible or relevant, are represented in an MME. While cognitive diversity can also be aimed at as a means to address the problem of epistemic injustice, this latter objective is quite likely to benefit also from social diversity defined as diversity of non-epistemic values.

In this matter, Rolin (2019) suggests an interesting avenue that we want to investigate in the case of MMEs. Rolin considers three approaches in what she refers to as "the social epistemology of diversity": Kitcher's distribution of research efforts, Longino's critical contextual empiricism, and Harding's feminist standpoint theory. Because Kitcher is interested in competing theories, and because we are interested in MMEs, we focus on the two other accounts.

4.2 Longino's objectivity

As made clear in Longino's account of "critical (contextual) empiricism" (1990; 2002), the evidential support for hypotheses is insufficient to guarantee objectivity because "the relation between hypotheses and evidence is mediated by background assumptions that themselves may not be subject to empirical confirmation or disconfirmation, and that may be infused with metaphysical or normative considerations" (1990, 75). As she argues, the more "transformative criticism" there is, the more objectivity there is in science. The extent to which "transformative criticism" is permitted depends upon the compliance with four criteria: (i) *Venues for criticism*: "There must be publicly recognized forums for the criticism of evidence, of methods, and of assumptions and reasoning" (2002, 129); these forums can be, for instance, journals or conferences; (ii) *Uptake of criticism*: "The community must not merely tolerate dissent, but its beliefs and theories must change over time in response to the critical discourse taking place within it" (2002, 129-130); (iii) *Public standards*: "There must be publicly recognized standards by reference to which theories, hypotheses, and observational practices are evaluated and by appeal to which criticism is made relevant to the goals of the inquiring community" (2002, 130); (iv) *Tempered equality of intellectual authority*: "Where consensus exists, it must be the result not just of the exercise of political or economic power, or of the exclusion of dissenting perspectives, but a result of critical dialogue in which all relevant perspectives are represented" (2002, 131).

The latter criterion, tempered equality of intellectual authority, explicitly calls for inclusivity within the scientific community – i.e., the inclusivity of various relevant domains of specific expertise – but also external participation in scientific debates as soon as the three other criteria are met. The scientists must be open to and respond to criticisms from inside and outside their community. Given the preconditions of being (i) expressed, heard and discussed in open forums, and (ii) taken into account with (iii) equal consideration, criticism from alternative points of views is likely to help identify, make visible and correct for dominant biases within background assumptions, as well as to provide arguments for a diversity of alternative perspectives. Hence, social diversity to some extent supports cognitive diversity in the sense that "the greater the number of different points of view included in a given community, the more likely it is that its scientific practice will be objective, that is, that it will result in descriptions and explanations of natural processes that are more reliable in the sense of less characterized by idiosyncratic subjective preferences of community members than would otherwise be the case" (Longino 1990, 80).

In Longino's account, social diversity is ensured by securing the engagement of diverse people with different social locations: the consultation and the participation of scientists belonging to underrepresented communities but also stakeholders including autochthonous people. The approach therefore aims at enlarging valuation to a broader group of people.

4.3 Harding's objectivity

A diversity of people may nevertheless not be enough for attaining valuable cognitive diversity (in addition to being too permissive, as it can include morally and politically problematic perspectives – see Rolin 2017, 2019). As Harding puts it in a note, regarding the detection of shared biases,

> Some might think this problem can be resolved by adding members of excluded groups into the community or by seeking more criticism within scientific processes. Efforts in these directions certainly can be helpful, but reflection on the Gould discussion suggests their limitations. Won't those "included" be only the well-socialized, least critical of the excluded? Are privileged groups likely to listen carefully to, and seriously value the distinctive perspectives of, groups that dominant institutions have devoted considerable effort to justifying as inferior? What kind of vigorous criticism should one expect to arise from a few junior (or even senior) colleagues who know well how their continued "inclusion", and the inclusion of those who follow them, depends on their "not making trouble"? (1995, note 6, 349)

Hence, we will now contend that strong objectivity in Harding's sense is a suitable framework for thinking about objectivity when dealing with epistemic inequality, because it starts with the "recognition of social inequality" (1995, 341) and the understanding of the way relations of power affect the production of scientific knowledge, while also being compatible with the model pluralism and ensemble-based inferences that characterise climate science.

In Harding's standpoint theory (Harding 1991, 1992, 1995, 2015), social diversity implies that one must think from the perspective of underrepresented or marginalised lives, where the latter are relevant cognitive sources from which to draw in order to have a better grasp of and critical look at the relations of power that shape the production of scientific knowledge.

> In order to gain a causal critical view of the interests and values that constitute the dominant conceptual projects, one must start one's thought, one's research project, from outside those conceptual schemes and the activities that generate them; one must start from the lives excluded as origins of their design – from "marginal lives." (1995, 342)

This approach is particularly relevant when addressing the problem of epistemic inequality, as it contains the idea that knowledge is situated and, in that sense, "knowledge is for and by a particular set of socially situated knowers" (Crasnow et al. 2018). The scientific questions, research agendas, and aspects of world referred to as a means to answer these questions therefore depend on the location of situated knowers.

In Longino's view, social diversity is diversity of social locations. In Harding's view, social diversity is diversity of standpoints. In Harding's account, however, the diversity of social (and, relevant to climate change, geopolitical) locations is neither a sufficient nor an exclusive approach for reaching diversity of standpoint. As made clear by Rolin, standpoints differ from social locations in that (i) situated knowers are able to point out the dominant social viewpoints that shape science, and (ii) standpoints are collective achievements that are (iii) produced by a sub-community of situated knowers sharing some common values. In other words, Harding's account demands an understanding of the mechanisms which create dominant viewpoints, as well as a process for producing standpoints within sub-communities. The sub-communities should therefore have possession of the elements of knowledge necessary to produce relevant standpoints.

4.4 Strong objectivity in climate science

One might object that an explicit enforcement of value diversity in the design of models and MMEs requires an administrative structure which would unavoidably interfere with the autonomy of research centers and potentially impair scientific creativity. We therefore promote a survey and study of the mechanisms which indirectly encourage strong objectivity and scientific equality. In this respect, model evaluation, more than model design, is a good place to start. A "Google scholar" search with keywords "CMIP5" and "evaluation" shows that in most cases the authors of evaluation studies are not the authors of the models. The production of the model is indeed partly decoupled from the analyses and evaluations of models and ensembles of models. One might assume that the result of these studies effectively feeds back into the model development, since once deficiencies are pointed out, they should attract the attention of modellers.

The production of the IPCC thematic and Assessment Reports provides another opportunity to promote strong objectivity (Jebeile 2020). Models are generally not prepared for a specific report (reports, in principle, survey the literature), but in the long run promoting epistemic diversity in the choice of IPCC thematic reports is likely to encourage modellers to produce models which appear to adequately address the questions raised by the thematic reports. In both thematic and regular Assessment Reports, the choice of graphical representations for comparing model performance on different criteria provides another powerful mechanism for appreciating and encouraging standpoint diversity.

The creation of standpoint diversity can also go along with the objective of achieving a diversity of social locations. Such diversity is promoted to some extent through international collaborations between diverse research teams, having the full range of scientific, technical and socio-economic views and perspectives, coming from different regions and from developed and developing countries and countries with economies in transition, but also reflecting diversity in gender representation and degrees of professional advancement.

The creation of various standpoints may be concretely achieved through the constitution of sub-communities of situated knowers (see also Rolin (2016) about the possible role of scientific/intellectual movements). In the case that concerns us, this could be achieved through the constitution of sub-communities within climate modelling programmes, which might comprise scientists belonging to underrepresented communities, who can be consulted to provide critical reflections on worldwide climate modelling developments and to point out shortcomings in addressing the needs and interests of certain regions and populations.

Scientists may ask other parties, such as policy-makers or citizen panels, to contribute to the development of model evaluation criteria. This process will help make scientists aware of possible common biases or dominant views that underlie their work, and is relevant even when the values that scientists choose are compatible with stakeholders' best interests. Forums may be constituted to reflect on worldwide climate modelling developments, and to point out shortcomings in addressing the needs and interests of certain regions and populations in the world.

That said, as Schroeder (2017) points out, asking scientists to communicate their outputs in accordance with the values of citizens, even though they may not share these values, is a form of moral burden. The possibility of consulting citizens and other stakeholders in the context of climate services has been investigated by Parker and Lusk (2019); Lusk (2020). In Lusk (2020), participatory democracy is even seen as a means to overcome the legitimacy problem that is posed by letting the values of modellers pervade scientific methods. Similarly, one might think that a public dialogue may help in addressing the needs of the different stakeholders within the models in an ensemble. This feedback may in turn help to overcome epistemic inequality.

Finally, technical progress may also help with the promotion of epistemic equality. The widespread use of satellite imagery or satellite-based products for model evaluation tends to promote equal attention to all regions of the globe. Model evaluation studies feature global maps which outline model deficiencies wherever they are located on the globe.

5 Conclusion

In this paper we have sought to address the problem of "epistemic inequality", recently highlighted by Parker and Winsberg (2018). We have promoted value management as a way to overcome this problem, an approach which becomes practicable provided one abandons the inductive risk arguments usually used as the reference framework in the discussions of value influence in climate science, and replaces them by social accounts of objectivity such as the notion of objectivity as defined by Longino or strong objectivity as defined by Harding. As we have shown, both accounts are relevant here because they are well adapted to the model pluralism and the ensemble-based inferences that characterise climate science. Strong objectivity appears to be better adapted to conceptually framing philosophical discussions of objectivity in climate modelling, and, incidentally, of the risk of epistemic inequality. Strong objectivity encourages a diversity of standpoints and values in knowledge production, and at the very least supports a form of value management that aims to avoid common biases, such as the predominance of *some* regional interests.

Value management is doubly beneficial: it is a promising means to remedy the disadvantage of certain communities regarding access to knowledge (the ethical benefit), as well as to reinforce objectivity (the epistemic benefit). It might turn out that value management will increase the spread of projections and thereby the quantified estimation of structural uncertainty, but we believe that including diverse views can make estimates of uncertainty more reliable by taking into account sources of uncertainty related to geographical and other representational shortcomings overlooked in previous models. We also think that other paradigmatic reasoning (e.g. possibilistic reasoning or storylines) are complementary and may well create more room for exploring extreme weather and climate conditions and phenomena.

The focus of this paper has thus lain between traditional philosophy of science and social epistemology, and to some extent on feminist epistemologies. We have recognised the role of the social dynamics of research in the epistemic properties of the mathematical representations that scientists develop. This role seems to be an important aspect of climate science, since models are intended to inform policy-makers with due regard to epistemic equality.

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